COMP 322: Fundamentals of Parallel Programming

Lecture 29: Introduction to the Message Passing Interface (MPI) cont.

Instructors: Vivek Sarkar, Mack Joyner
Department of Computer Science, Rice University
{vsarkar, mjoyner}@rice.edu

http://comp322.rice.edu/

COMP 322 | Lecture 29 | 29 March 2017

Worksheet #28 solution: MPI send and receive

```
1. int a[], b[];
2. ...
3. if (MPI.COMM_WORLD.rank() == 0) {
4.    MPI.COMM_WORLD.Send(a, 0, 10, MPI.INT, 1, 1);
5.    MPI.COMM_WORLD.Send(b, 0, 10, MPI.INT, 1, 2);
6. }
7. else {
8.    Status s2 = MPI.COMM_WORLD.Recv(b, 0, 10, MPI.INT, 0, 2);
9.    Status s1 = MPI.COMM_WORLD.Recv(a, 0, 10, MPI_INT, 0, 1);
10.   System.out.println("a = " + a + " ; b = " + b);
11.}
12. ...
```

Question: In the space below, indicate what values you expect the print statement in line 10 to output (assuming the program is invoked with 2 processes).

Answer: Nothing! The program will deadlock due to mismatched tags, with process 0 blocked at line 4, and process 1 blocked at line 8.

mpiJava vs. OpenMPI Java API

- mpiJava is a standalone and prototype Java library developed 10+ years ago as part of the HPJava project at Indiana University
- OpenMPI is a large consortium of universities/companies building an open-source implementation of the MPI programming model
  - —Recently added Java APIs, similar to mpiJava (but more modern)
  - —We will use mpiJava in lecture slides, but OpenMPI for Lab 10 and Homework 5

	mpiJava	OpenMPI Java API
Package name	package mpi	package mpi
Main class	mpi.MPI	mpi.MPI
Get MPI Rank	MPI.COMM_WORLD.Rank()	MPI.COMM_WORLD.getRank()
Get # MPI Ranks	MPI.COMM_WORLD.Size()	MPI.COMM_WORLD.getSize()
Send MPI Msg	MPI.COMM_WORLD.Send(…)	MPI.COMM_WORLD.send(…)
Recv MPI Msg	MPI.COMM_WORLD.Recv(…)	MPI.COMM_WORLD.recv(…)

Outline of today's lecture

- Blocking communications (contd)
- Non-blocking communications
- Collective communications

Basic Datatypes

- mpiJava defines 9 basic datatypes: these correspond to the 8 primitive types in the Java language, plus the MPI.OBJECT datatype that stands for an Object (or, more formally, a Java reference type).
  — MPI.OBJECT value can only be dereferenced on process where it was created
- The basic datatypes are available as static fields of the MPI class. They are:

mpiJava datatype	Java type
MPI.BYTE	byte
MPI.CHAR	char
MPI.SHORT	short
MPI.BOOLEAN	boolean
MPI.INT	int
MPI.LONG	long
MPI.FLOAT	float
MPI.DOUBLE	double
MPI.OBJECT	Object

Communication Buffers

- Most of the communication operations take a sequence of parameters like

  Object buf, int offset, int count, Datatype type

- In the actual arguments passed to these methods, buf must be an array (or a run-time exception will occur).

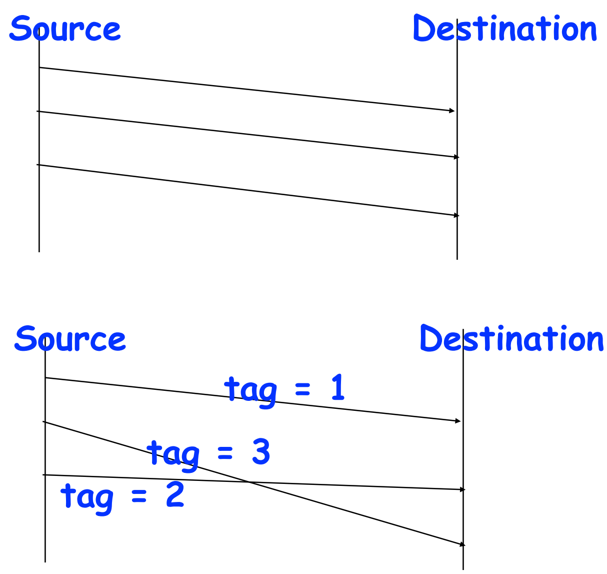
Would need to override with 8 versions of methods using 1 buffer

void Send(int[] buf, …)
void Send(long[] buf, …)

Would need to override with 64 versions of methods using 2 buffers

void Reduce(int[] sbuf, …int[] rbuf)
void Reduce(int[] sbuf, …long[] rbuf)

Message Ordering in MPI



- FIFO ordering only guaranteed for same source, destination, data type, and tag
- In HJ actors, FIFO ordering was guaranteed for same source and destination
  - Actor send is also “one-sided” and “non-blocking” (unlike send/recv in MPI)

Layout of Buffer

- If type is a basic datatype (corresponding to a Java type), the message corresponds to a subset of the array buf, defined as follows:

  - In the case of a send buffer, the red boxes represent elements of the buf array that are actually sent.
  - In the case of a receive buffer, the red boxes represent elements where the incoming data may be written.

Scenario #1

Consider:

```
int a[], b[];
...
if (MPI.COMM_WORLD.rank() == 0) {
    MPI.COMM_WORLD.Send(a, 0, 10, MPI.INT, 1, 1);
    MPI.COMM_WORLD.Send(b, 0, 10, MPI.INT, 1, 2);
}
else {
    Status s2 = MPI.COMM_WORLD.Recv(b, 0, 10, MPI.INT, 0, 2);
    Status s1 = MPI.COMM_WORLD.Recv(a, 0, 10, MPI_INT, 0, 1);
}
...
```

Blocking semantics for Send() and Recv() can lead to a deadlock.

Approach #1 to Deadlock Avoidance --- Reorder Send and Recv calls

We can break the circular wait in the worksheet by reordering Recv() calls to avoid deadlocks as follows:

```
int a[], b[];
...
if (MPI.COMM_WORLD.rank() == 0) {
    MPI.COMM_WORLD.Send(a, 0, 10, MPI.INT, 1, 1);
    MPI.COMM_WORLD.Send(b, 0, 10, MPI.INT, 1, 2);
}
else {
    Status s1 = MPI.COMM_WORLD.Recv(a, 0, 10, MPI_INT, 0, 1);
    Status s2 = MPI.COMM_WORLD.Recv(b, 0, 10, MPI.INT, 0, 2);
}
...
```

Scenario #2

Consider the following piece of code, in which process i sends a message to process i + 1 (modulo the number of processes) and receives a message from process i - 1 (modulo the number of processes)

```
int a[], b[];
. . .
int npes = MPI.COMM_WORLD.size();
int myrank = MPI.COMM_WORLD.rank()
MPI.COMM_WORLD.Send(a, 0, 10, MPI.INT, (myrank+1)%npes, 1);
MPI.COMM_WORLD.Recv(b, 0, 10, MPI.INT, (myrank+npes-1)%npes, 1);
```

Question: does this MPI code deadlock?

Approach #2 to Deadlock Avoidance --- a combined Sendrecv() call

- Since it is fairly common to want to simultaneously send one message while receiving another.
- In mpiJava, the Sendrecv() method has the following signature:

```
Status Sendrecv(Object sendBuf, int sendOffset, int sendCount,
        Datatype sendType, int dst, int sendTag,
        Object recvBuf, int recvOffset, int recvCount,
        Datatype recvType, int src, int recvTag) ;
```

More efficient than separate sends and receives

Can avoid deadlock

— There is also a variant called Sendrecv_replace() which only specifies a single buffer

Using Sendrecv for Deadlock Avoidance in Scenario #2

Consider the following piece of code, in which process i sends a message to process i + 1 (modulo the number of processes) and receives a message from process i - 1 (modulo the number of processes)

```
int a[], b[];
. . .
int npes = MPI.COMM_WORLD.size();
int myrank = MPI.COMM_WORLD.rank()
MPI.COMM_WORLD.Sendrecv(a, 0, 10, MPI.INT, (myrank+1)%npes, 1,
                    b, 0, 10, MPI.INT, (myrank+npes-1)%npes, 1);

...
```

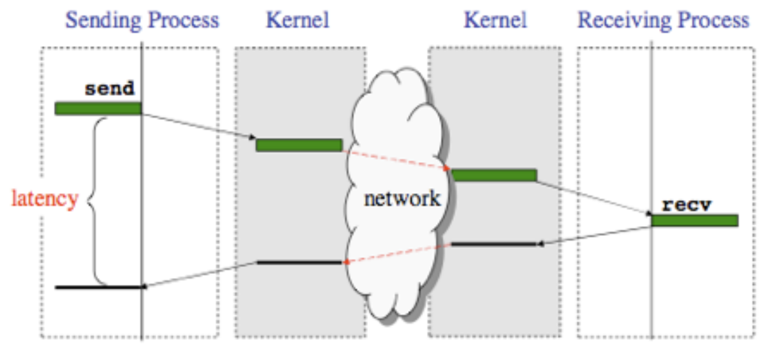
A combined Sendrecv() call avoids deadlock in this case

Outline of today's lecture

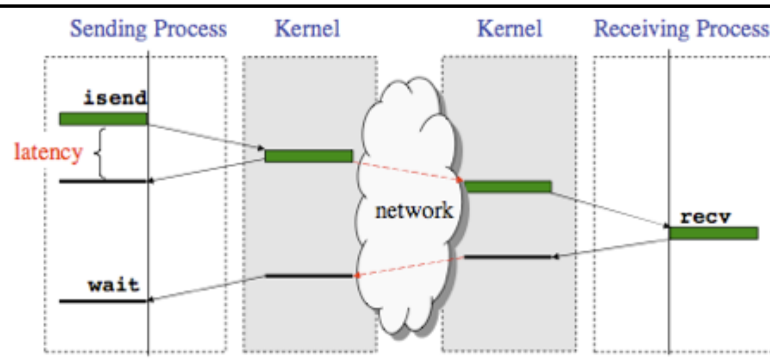
- Blocking communications (contd)
- <u>Non-blocking communications</u>
- Collective communications

Latency in Blocking vs. Nonblocking Communication

Blocking communication



Nonblocking communication (like an async or future task)



Non-Blocking Send and Receive operations

- In order to overlap communication with computation, MPI provides a pair of functions for performing non-blocking send and receive operations ("I" stands for "Immediate")

Request Isend(Object buf, int offset, int count, Datatype type, int dst, int tag) ;
Request Irecv(Object buf, int offset, int count, Datatype type, int src, int tag) ;

- Use Wait() to wait for operation to complete (like future get).

Status Wait(Request request)

- The Wait() operation is declared to return a Status object. In the case of a non-blocking receive operation, this object has the same interpretation as the Status object returned by a blocking Recv() operation.

Simple Irecv() example

- The simplest way of waiting for completion of a single non-blocking operation is to use the instance method Wait() in the Request class, e.g:

```
// Post a receive (like a "communication async")
Request request = Irecv(intBuf, 0, n, MPI.INT,
                 MPI.ANY_SOURCE, 0) ;
// Do some work while the receive is in progress
…
// Wait for message to arrive (like a future get)
Status status = request.Wait() ;
// Do something with data received in intBuf
…
```


Waitall() vs. Waitany()

public static Status[] Waitall (Request [] array_of_request)

- Waitall() blocks until all operations associated with the active requests have completed.
- Returns an array of statuses for each of the requests.
  - Waitall() is a like a finish scope for all requests in the array

public static Status Waitany(Request [] array_of_request)

- Waitany() blocks until one of the operations associated with the active requests has completed.
  - Source of nondeterminism

Outline of today's lecture

- Blocking communications (contd)
- Non-blocking communications
- <u>Collective communications</u>

Collective Communications

- A popular feature of MPI is its family of collective communication operations.
- Each collective operation is defined over a communicator (most often, MPI.COMM_WORLD)

— Each collective operation contains an *implicit barrier*. The operation completes and execution continues when all processes in the communicator perform the *same* collective operation.

— A mismatch in operations results in *deadlock* e.g.,

Process 0: .... MPI.Bcast(...) ....

Process 1: .... MPI.Bcast(...) ....

Process 2: .... MPI.Gather(...) ....

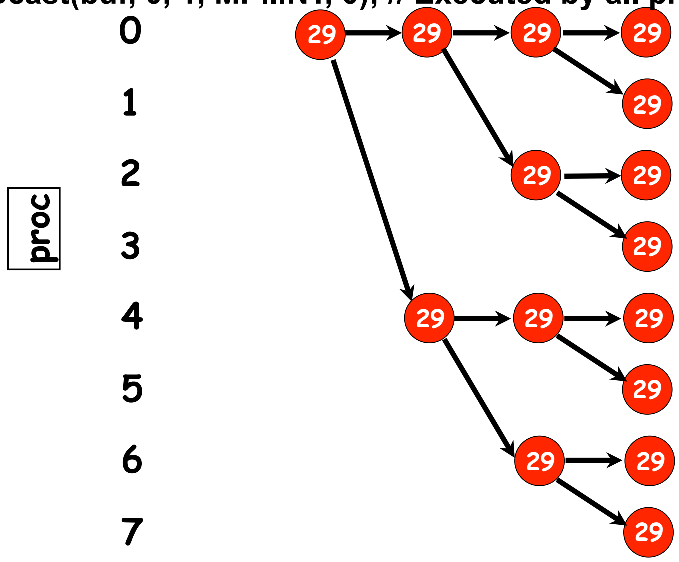
- A simple example is the broadcast operation: all processes invoke the operation, all agreeing on one root process. Data is broadcast from that root.

```
void Bcast(Object buf, int offset, int count, Datatype type, int root)
```

MPI_Bcast

buf = new int[1]; if (rank==0) buf[0] = 29;

void Bcast(buf, 0, 1, MPI.INT, 0); // Executed by all processes



A root process sends same message to all

29 represents an array of values

Broadcast can be implemented as a tree by MPI runtime

More Examples of Collective Operations

void Gather(Object sendbuf, int sendoffset, int sendcount,
Datatype sendtype, Object recvbuf, int recvoffset, int recvcount,
Datatype recvtype, int root)

- Each process sends the contents of its send buffer to the root process.

void Scatter(Object sendbuf, int sendoffset, int sendcount,
Datatype sendtype, Object recvbuf, int recvoffset, int recvcount,
Datatype recvtype, int root)

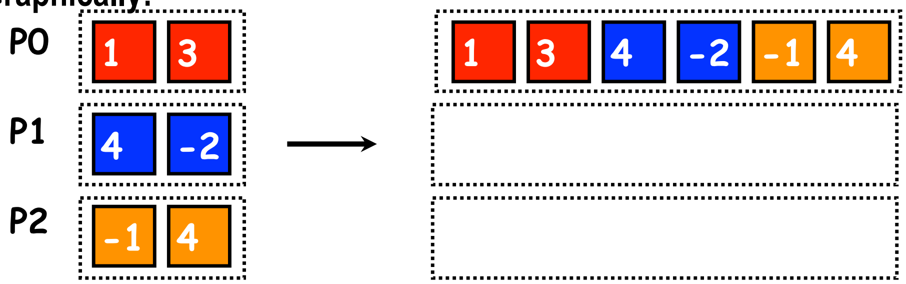
- Inverse of the operation Gather.

void Reduce(Object sendbuf, int sendoffset, Object recvbuf, int recvoffset,
int count, Datatype datatype, Op op, int root)

- Combine elements in send buffer of each process using the reduce operation, and return the combined value in the receive buffer of the root process.

MPI_Gather

- Use to copy an array of data from each process into a single array on a single process.
- Graphically:



- Note: only process 0 (P0) needs to supply storage for the output

```
void Gather(Object sendbuf, int sendoffset, int sendcount,
        Datatype sendtype, Object recvbuf, int recvoffset,
        int recvcount, Datatype recvtype, int root)
```

– Each process sends the contents of its send buffer to the root process.

Predefined Reduction Operations

Operation	Meaning	Datatypes
MPI_MAX	Maximum	int, long, float, double
MPI_MIN	Minimum	int, long, float, double
MPI_SUM	Sum	int, long, float, double
MPI_PROD	Product	int, long, float, double
MPI_LAND	Logical AND	int, long
MPI_BAND	Bit-wise AND	byte, int, long
MPI_LOR	Logical OR	int, long
MPI_BOR	Bit-wise OR	byte, int, long
MPI_LXOR	Logical XOR	int, long
MPI_BXOR	Bit-wise XOR	byte, int, long
MPI_MAXLOC	max-min value-location	Data-pairs (see next slide)
MPI_MINLOC	min-min value-location	Data-pairs

MPI Reduce

```
void MPI.COMM_WORLD.Reduce(
        Object  sendbuf        /* in */,
        int             sendoffset      /* in */,
        Object  recvbuf        /* out */,
        int             recvoffset      /* in */,
        int             count           /* in */,
        MPI.Datatype    datatype        /* in */,
        MPI.Op operator        /* in */,
        int             root            /* in */ )
```


```
MPI.COMM_WORLD.Reduce(msg, 0, result, 0, 1, MPI.INT, MPI.SUM, 2);
```